Optimizing the Energy Deposition in the Pbar Target by Beam Sweeping

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An accurate estimate of total and maximum energy deposition in the present pbar target of FNAL is one of the most important aspects in developing future proton beam sweeping system to increase phase space and intensity of pbar yield. This also helps to workout some of the limiting requirements. Several Monte Carlo programs[1] are available to study hadronic and electromagnetic cascades when a high energy particle interacts with thick targets. In spite of different interaction models in these codes, results of calculation on energy deposition in the pbar target agree well as was shown recently in ref. 2. MARS10[1] is one of sophisticated computer code which uses inclusive approach for simulation of hadron cascades and can be used to study accelerator related problems. Using this program a number of calculations have been performed here to study pbar target for 120GeV proton beam.

This brief report presents i) an estimate of present maximum energy deposition E_{max} in the target, ii) E_{max} as a function of sweeping radius, and iii) A design requirement to build kicker magnets to sweep the proton beam on the target.

At present, the average $N_p = 1.72\text{x}10^{12}$ protons per pulse (ppp) at 120GeV are being used to produce pbar from the copper target. About $1.0\text{x}10^{7}$ pbars per proton pulse are being stacked in the accumulator. Figure 1 shows SEM picture of a typical proton beam pulse interacting the target. Then average beam spot size given by,

$$\sigma = \sqrt{\frac{\sigma_x^2 + \sigma_y^2}{2}}$$

is 0.0155 cm. Some results of Monte Carlo calculations indicating longitudinal distribution of energy deposition in copper target of 7.0cm length is shown in Fig. 2(a). The radial distributions up to $r=7\sigma/2$ have also been presented here (the estimated errors on ϵ are upto 20%.). This suggests that the ϵ_{max} is 2.1 GeV/gm/p for beam spot size σ =.015 cm and is at a thickness of 4.0cm $\leq$ Z $\leq$ 7.0cm along the beam axis. (These calculations also suggest that the temperature of the target in this region is 1327$\pm$272°C. Within errors this is 1083°C, melting temperature of copper under normal pressure.). Therefore, presently maximum energy deposited

$$E_{max} = 1.602\epsilon_{max}N_p10^{-10}(Joule/gm)$$

is 579 Joule/gm (in the past six to seven months E_{max} was grater than 600Joule/gm quite often and target does not seem to be distorted). This is about three times larger than the previous limit[3] determined on metal targets as 200 Joule/gm (which seems to be a better limit for tungsten targets based on our experience). This discrepancy may arise because the high temperature behaviour of the metals has to be taken into account in more accurate theoretical estimations. Previously there was no systematic experimental investigation to find out the tolerable beam intensity on copper target. Therefore, it may be interesting to measure the limiting energy density deposition on the copper target by increasing the intensity of the proton beam. At present about 600 Joule/gm could be taken as an allowable E_{max}.

One of the future plan in upgrading TEVATRON facility includes increasing pbar production rate by decreasing the beam spot size and by increasing ppp. The proton beam of spot size $\sigma = 0.010$cm found to show optimum phase space density for pbar[4] and we assume upgrade of Booster and Main ring would give up to ppp = 5.0x 10^{12} on the target. By this the pbar phase space density will be increased by about 15% and pbar per pulse by about a factor of three higher than the present value. Calculations have shown(see e.g. Fig. 2(b)) that for this beam condition the maximum energy density deposition per pulse will be 2800 Joule/gm and the temperature of the cell could be increased upto 5800^{o}C (one may notice that the boiling points of copper under normal pressure is 2567^{o}C). Previously, it has been suggested [5-7] that under these conditions sweeping the beam on the target circularly could reduce maximum energy density deposition. Sweeping parallel to beam axis can be achieved using two kicker magnets in the upstream of the target and match this with another set of kickers after the Li-lens so that whatever displacement was given to the beam from the first will be compensated by second to put the beam back into its normal path.

Figure 3 shows a maximum energy density deposited in the taret as a function of sweeping radius. This shows that to keep $E_{max} \leq$ 600Joule/gm the preferable sweeping radius $R_{sweep} \geq 0.035$cm.

To provide one of the essential design requirement to kicker magnets some knowledge of beam structure along beam axis may be essential. For every two seconds one booster batch of protons in approximately 83 RF buckets will be accelerated to 120GeV. Figure 4 shows a typical time behavior of the main ring beam pulse just before it interacts with the target. This clearly shows that the number of protons in each RF bucket is approximately equal. Then the number of protons interacting any particular region of the target is a linear function of time within beam spill time ($\approx 1.6\mu$sec). Figure 5 shows maximum energy deposited along the beam path in the target as a function of time for different beam spot sizes. For $\sigma = 0.010$cm the beam deposits about 600 Joule/gm within 0.33μsec. So to keep the peak energy deposition in the target less than 600 Joule/gm the beam has to be displaced by about 2σ within this time. This gives a minimum beam sweeping velocity $v_{sweep} = \frac{2\sigma}{\Delta t} = 6.0 \times 10^4$ cm/sec. If R_{sweep} is choosen to be 0.035cm and during 1.6μsec the proton beam sweeps a circle once on the target then the beam sweeping velocity will be about 2.4 times faster than the above limit. In practice the sweeping radius could be slightly smaller than the limit determined previously because copper being a good conductor of heat and target could be cooled continuously at a fixed rate. To determine the limits arising from target cooling calculations should include the thermal behaviour of the target. However as a first step one might take R_{sweep} =0.035 cm and beam sweeping along a circle within a beam spill time.

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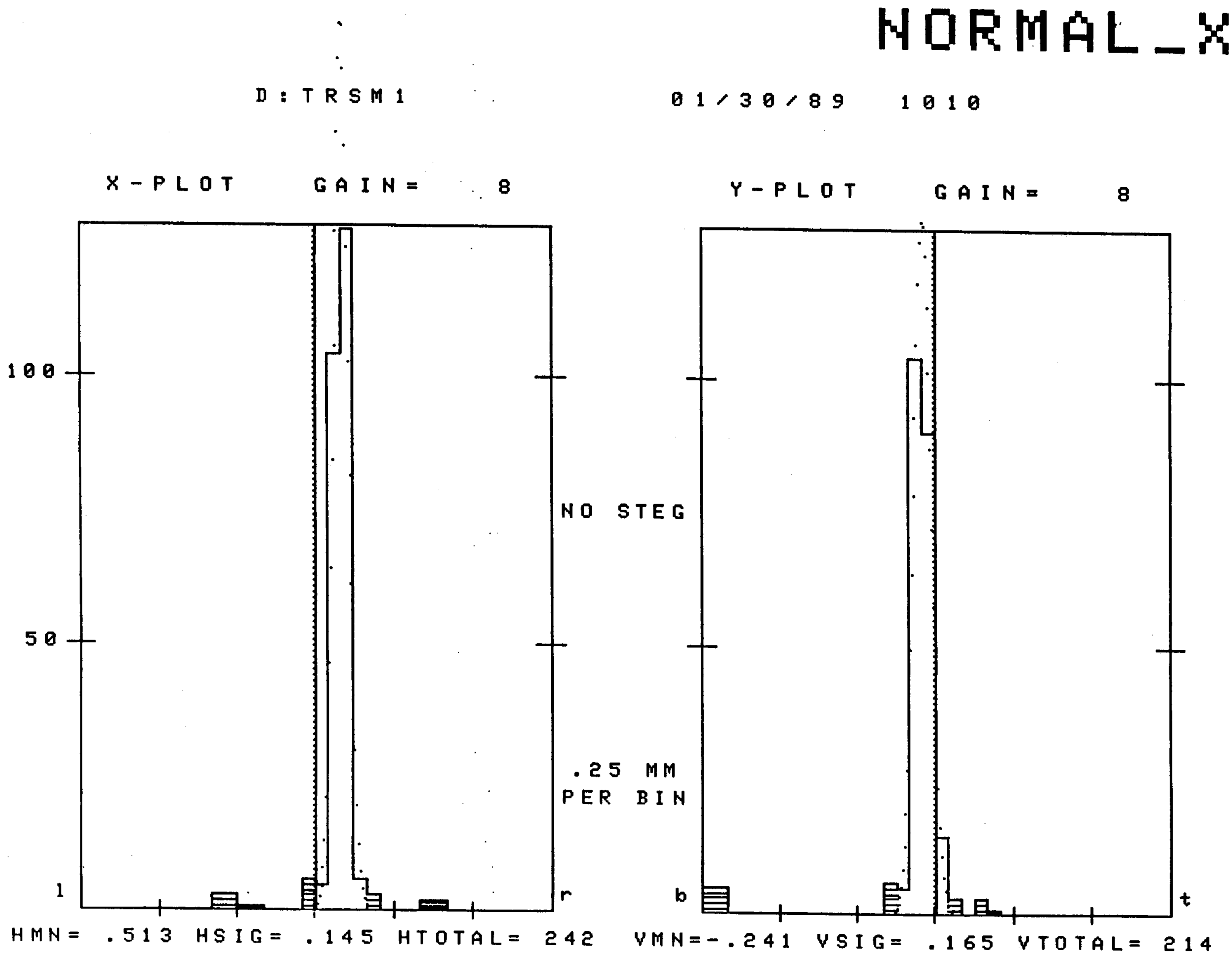

Fig. 1. SEM picture of the Main ring proton beam pulse just before the target.

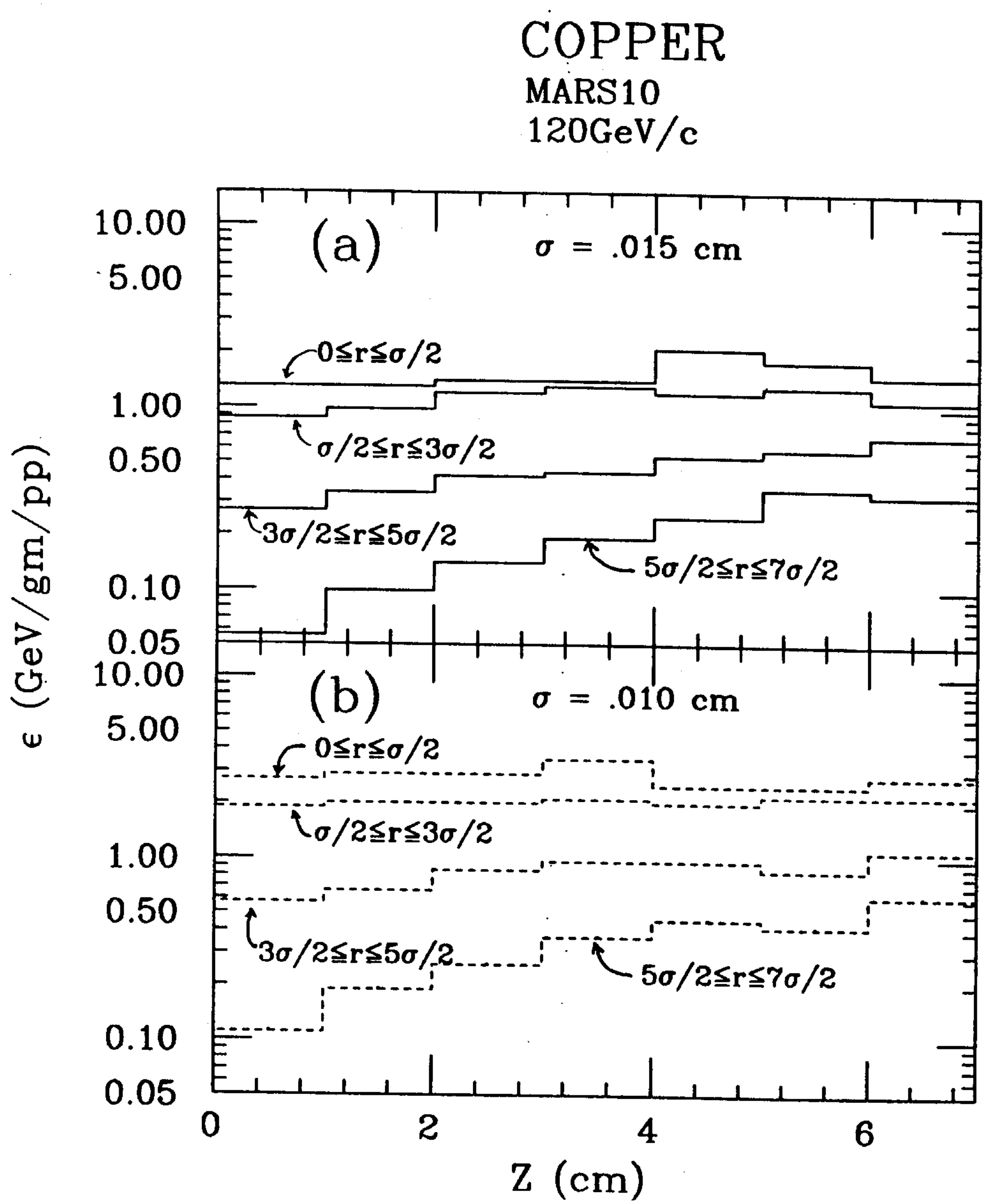

Fig. 2. Enegry density distribution in the 7cm long target for beam spot sizes (a) σ=0.015cm and (b) σ=0.010cm. Data only up to r=$7\sigma/2$ is shown.

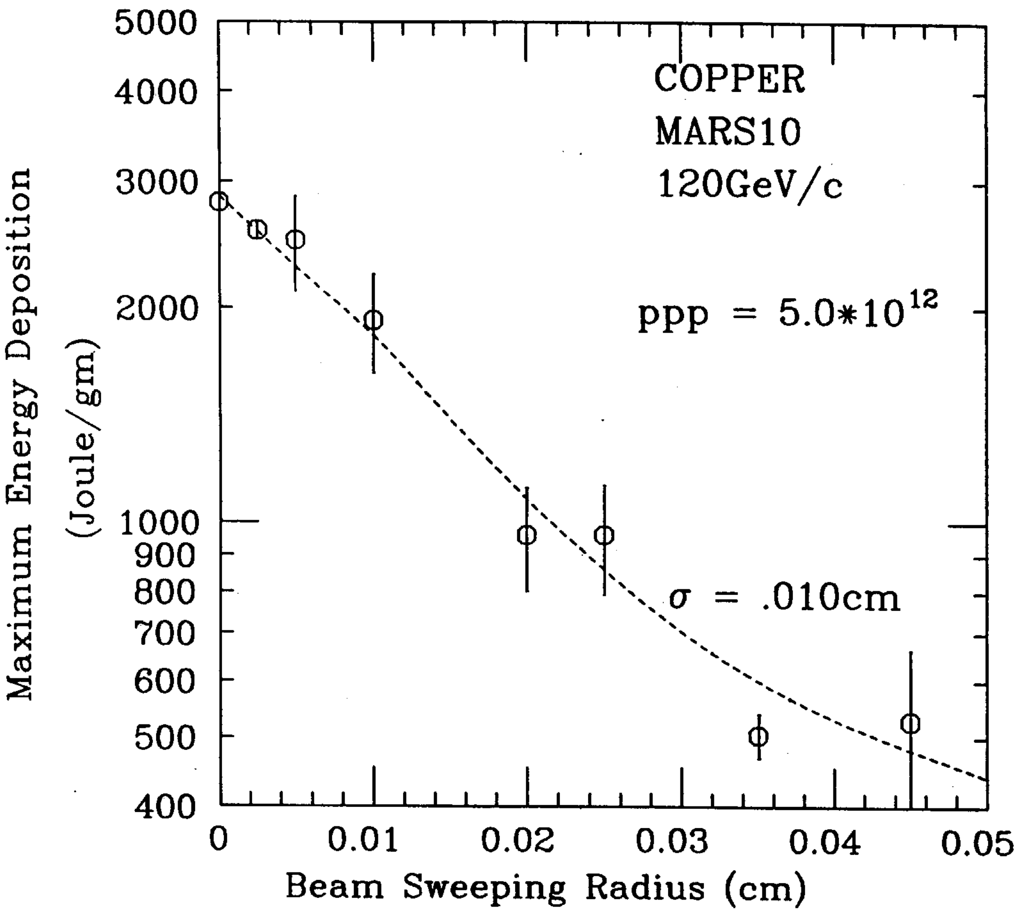

Fig.3 Maximum energy deposition verses beam sweeping radius. Verticle bars represent statistical errors. The curve is drown to guide the eye.

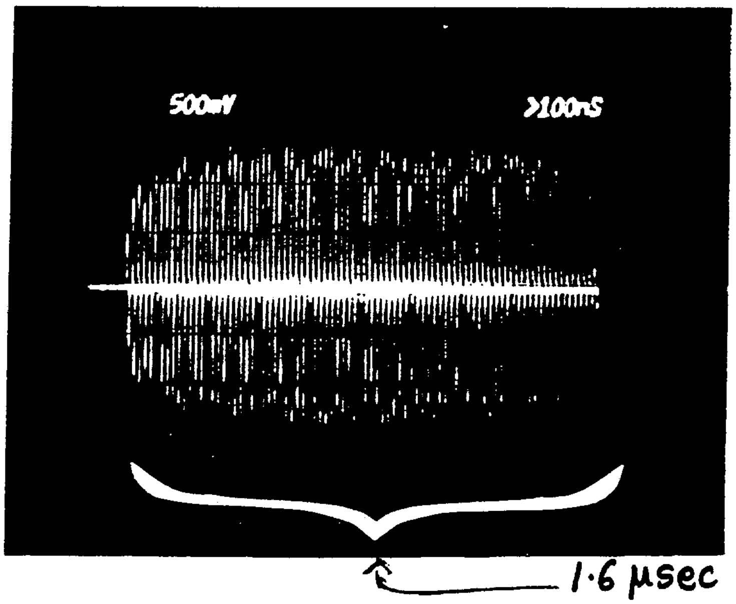

Fig. 4. Protons bunch in 83 RF buckets after five turns just before extraction for trageting. The total length is 1.6μsec.

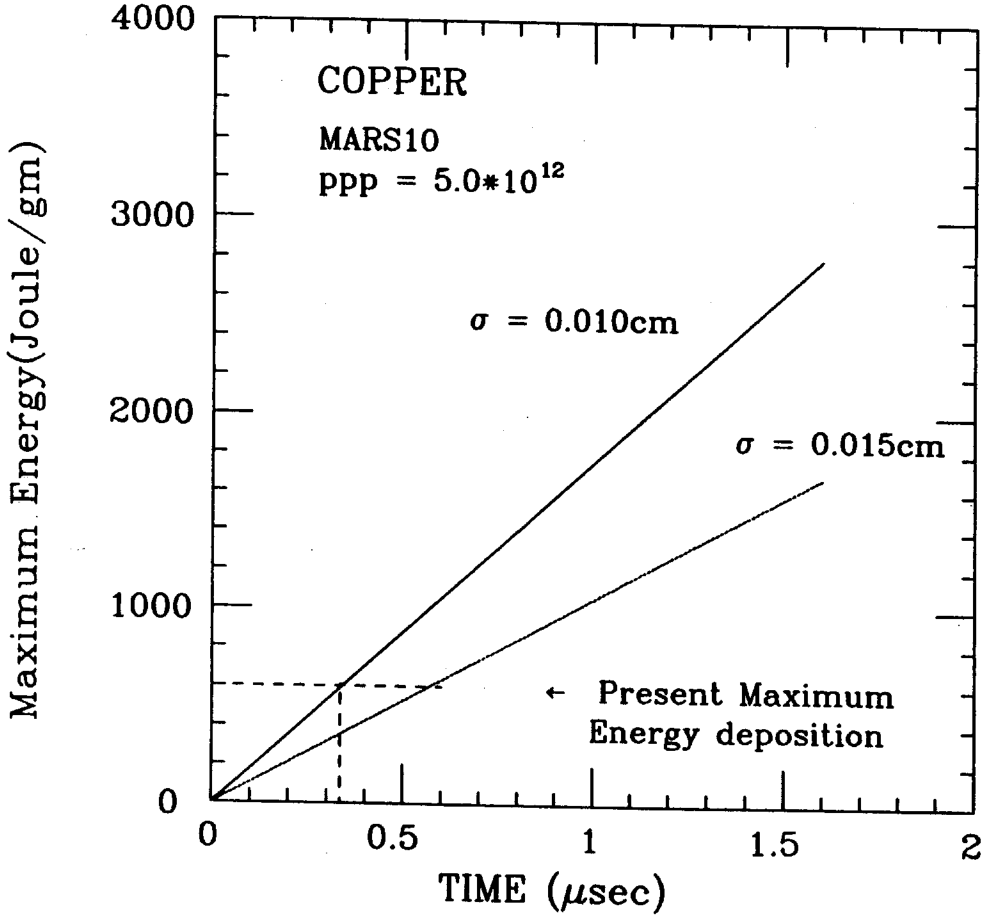

Fig. 5. Maximum energy deposition as a function of time in the target for beam spot sizes σ=0.015cm and σ=0.010cm. Number of protons in the pulse is 5x10^{12}.